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Performance of a passive small-plot runoff collector under laboratory and field conditions

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Signatures have been redacted for privacy

To Nick and my family.

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CHAPTER 1. LITERATURE REVIEW

EROSION AND RUNOFF

In the United States the most prevalent soil degradation process is accelerated erosion driven by anthropogenic activities (Lal et al., 2003). The Natural Resources Inventories (N.R.I.) estimated that 1 million tons of sediment was lost in 2001 from agricultural fields across the United States (N.R.I., 2003). Erosion loss is expedited in the Midwest by intensive row crop monocultures which dominate the landscape. Iowa has the greatest area 1.26 million acres (0.51 Mha) relative to other states with severely eroded land, defined as land annually experiencing >4 tons soil loss/acre (NRI 1992 as cited by Lal et al. 2003).

Sediment and constituents move with surface water, or runoff, across eroding fields and wreak potential havoc in water bodies. The Environmental Protection Agency has indicated that erosion derived sediment, primarily from agriculture production, is the second leading cause of water quality impairment in rivers and lakes (EPA 1995 as cited by Uri and Lewis, 1999). On-site erosion can cause a production decline due to lost topsoil. Off-site erosion damage affects numerous resources. Suspended soil particles decrease the transmission of sunlight, raise water temperatures and negatively impact aquatic life respiration and digestion. Sediment-laden water also poses problems for water treatment facilities, which must filter particles from drinking water supplies. Increased sediment load also reduces reservoir capacity and aesthetic quality of recreation sites, in addition to clogging navigation and conveyance systems (Uri and Lewis, 1999).

CONSERVATION TILLAGE

In recent years, there has been a gradual shift towards conservation tillage systems. In a 2002 Conservation Technology Information Center report, Iowa led the nation in conservation tillage; roughly 12.8 million acres are under conservation tillage practices, which accounts for 56% of total cropped land in Iowa. Since 1990 the acreage of conservation tillage practices has increased by more than 275% (Greiner, 2003). Conservation tillage systems leave residue on the soil surface (at least 30% of the surface covered with crop residue after spring planting), thus protecting the valuable soil resource underneath. According to Mueller et al. (1984) residue and the subsequent rough surface reduces sediment concentration and in some cases runoff water volume.

Laflen et al. (1978) reported that residue cover had a strong relationship with sediment concentration and soil loss; in two of three soil types studied, runoff amounts and residue cover had an inverse relationship. Runoff in the study ranged from 15 to 17 cm for conventional tillage on two soil types and from 12 to 15 cm for the same two soils under conservation tillage treatment. The sediment losses for the same treatments ranged from 25-30 PPM x10^3 for conventional to 1-2 PPMx10^3 for conservation tillage. Results from Johnson et al. (1979) show that conservation tillage systems reduced runoff by roughly 40 percent and sediment loss by 60-90 percent relative to conventional tillage on six small paired watersheds. Soil loss varied from 31.5 ton/ha/yr to 12 t/ha/yr for conventional and till-plant, respectively.

However, other research has reported conflicting results. In field plots in Wisconsin, Mueller et al. (1984) found significantly lower runoff loss from chisel and conventional systems immediately after planting relative to no-till systems. They attribute variable results among studies to surface condition differences at sampling, such as surface sealing. Ghidey and Alberts (1998) had similar conclusions from chiseled and no-till treatments over a long-term study. They found no-till increased mean annual runoff by 20%, but annual sediment loss was only 20% of that for chiseled treatments. It is clear that additional research is needed to identify factors which may lead to conflicting results.

SOURCES OF VARIABILITY

A challenge facing soil erosion and runoff research is the large, unexplained unpredictability in field plot measurements. The variability is a result of both natural variability and measurement inconsistency (Nearing et al., 1999). This can cause complications in data extrapolation for soil loss prediction models because it is arduous to differentiate between errors introduced by the model from the error resulting from measured value variability. Ruttiman et al. (1995) experienced coefficient of variation (COV) ranging from 3.4% to 173.2% for soil loss and from 8.1% to 104.7% for runoff from 54 apparently homogeneous test plots. Wendt et al. (1985) reported lower COV (20%) with the exception of small natural rainfall events in 40 essentially uniform plots for both runoff and soil loss.

Nearing et al. (1999) analyzed replicated plot pairs for 2061 storms, 797 annual erosion measurements and thirteen different soil types and site locations. The estimated COV of within-treatment plot replicate values of measured soil loss ranged on the order of 14% for a measured soil loss of 20kg/m^2 to greater than 150% for measured soil loss of less than 0.01 kg/m^2. They conclude that the "coefficient of variation in soil erosion data tends to be much greater when measured soil loss values are relatively small." Soil loss magnitude is a critical aspect for explaining variance in soil loss data. Edwards and Owens (1991) found in a 28-year, nine watershed study, that three of the largest erosion-producing storms on each watershed accounted for more than 50% of the total measured soil loss.

It is difficult to separate factors influencing soil erosion in field plot measurements due to complex interactions. Wischmeier and Mannering (1969) state that "no single parameter or interaction term proved capable of a soil's resistance to erosion by rainfall and runoff." They claim numerous soil properties have an impact on erodibility such as soil structure and texture, bulk density, pH, and slope characteristics (shape, length and steepness). Cropping system and canopy, variable residue, snow cover, and frost distribution may also cause variability (Gard and Doren, 1949). Soil loss results vary considerably even under rainfall simulators which permit storm event replication (Bryan, 1981). Raindrop size and intensity, surface water films and aggregate stability were noted in the study to affect results. A portion of the variability is due to measurement error, such as collector performance bias. However, Wendt et al. (1985) concluded that collector bias was not a major source of unexplained inconsistency.

To identify sources of variability and to alleviate confounding factors it is necessary to use numerous replications. Nearing et al. (1999) notes a dearth of research with adequate replications to allow statistical evaluation of unexplained variability. Other studies (Ruttimann et al., 1995; Wendt et al., 1985) state that several replications are needed to accurately estimate mean runoff and erosion losses for adequate comparisons.

FIELD SAMPLING

Controversies over water quality degradation due to agriculture practices make research critical to correctly identify sources and avoid misinformation. Vigilant care that runoff and erosion samples are representative of total runoff is crucial to make these advances (Willis et al., 1969). Runoff and soil loss must continue to be quantified between conventional and conservation tillage systems; this is the role that runoff collector research must assume. Emphasis must be placed on producing reliable data that is collected by a standard and reproducible methodology (Lal et al., 2003). Measurement data is also critical for the verification of erosion prediction models which allow natural resource personnel to make recommendations to farmers.

Runoff research using small plots to quantify soil and water losses due to rainfall has taken place in the United States since 1917; the project objectives have typically been to evaluate soil and/or water runoff losses associated with a cropping or management system (Mutchler, 1963). Additional research is needed; evaluation of soil and water runoff on spatial and temporal scales in producer fields will allow more rigorous tests and possible improvements of existing soil erosion and water runoff models. Lerch et al. (2005) found that the majority of sediment, nutrient and herbicide loss occurred in one area of a 36 ha (89 ac) field. They conclude that soil loss spatial variability over the last century influences the soil and water quality, and crop productivity patterns currently observed in that field. In order to gain a better understanding of soil movement and runoff, collector studies under natural conditions are necessary.

COLLECTOR CRITERIA

To most easily achieve large data sets with numerous plot measurements, collector type selection becomes critical. It is essential to plan for long-term maintenance and ease of operation during collector design considerations (Mutchler, 1963). For economic feasibility, field measurements of soil erosion must be kept simple. Test site selection, sampling procedure simplicity, adequate observations and the statistical analysis of data should be the focus rather than sophisticated instrumentation (Holton et al., 1962; Ruttimann et al., 1995). It is logical that the chosen collector must be adaptable to variable field and climatic situations, mobile, affordable and easy to use.

COLLECTOR TYPES

There are numerous types of runoff collectors available. The majority of collectors are unique due to area specific requirements, such as frost occurrence and slope (Mutchler, 1963). Some standard designs are commercially available, but even this demands careful contemplation of equipment selection and installation requirements. According to Laflen (2003) runoff collector systems fall into three categories: collectors which sample a constant fraction of the total flow over an entire event; systems that collect samples at a given time or flow volume interval; or those which require manual sample collection or the entire runoff amount is collected for sampling. Numerous studies (Cullum et al., 1992; Eisenhauer et al., 2002; Klik et al., 2004) employ sophisticated equipment to obtain detailed soil erosion and runoff data at the expense of limited project budgets and replications.

For this research project, the focus will be on an economical and passive system which collects a variable fraction of runoff depending on storm event size and runoff quantities. These are useful when the objective is a relative comparison between management practices. Disadvantages are plot size limitations and lack of information regarding temporal changes during the event (Laflen, 2003). Mutchler (1963) described a multislot divisor design based on the assumption of even sheet flow throughout the collector body. Runoff is divided into equal proportions as it flows through several parallel slots and an aliquot is collected from one. The success of the collector was attributed to the sludge tank, in which sediment settles.

Sheridan et al. (1996) described an economical, low-impact flow event (LIFE) sampler designed to collect surface flow volume estimates and composite samples for laboratory analysis of dissolved and suspended constituents without significant disturbance to vegetative cover and ground surface. A modified version of the LIFE collector was used by Franklin et al. (2001) to accommodate larger runoff events. They conclude that this collector is unobtrusive, inexpensive and can be used to gain insight about nutrient and constituent movement across the landscape. With inexpensive and straightforward instrumentation, numerous replications can be used. However, the modification of the design used by Franklin et al. (2001) used in previous research (Eleki, 2003) studies had limitations. Although the collector had several favorable attributes, it had a fixed capacity that limited its flexibility of use on plot size and runoff volumes. Plot size of interest varies with spatial studies and runoff volumes can vary significantly with rainfall intensity and duration; therefore, a runoff collector with attributes of the LIFE system, in addition to added flexibility relative to runoff volume capacity, is needed. The design should allow for collection of an adequate runoff sample for suitable analysis from small runoff events, while maintaining the capacity for large events.

The objective of this research is to design a low-cost, passive, small plot runoff and sediment collector with the capacity to handle variable sized runoff events.

CHAPTER 2. PERFORMANCE OF A PASSIVE SMALL-PLOT RUNOFF COLLECTOR UNDER LABORATORY AND FIELD CONDITIONS

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ABSTRACT

Large variability in soil erosion and water runoff in the field necessitates numerous replications in order to evaluate differences between treatments. One method for addressing this challenge is to use a simple, low-profile runoff collector that is adaptable to large and small runoff events. A runoff collector was designed to obtain representative soil and runoff loss measurements from small field plots with the capacity to store sediment and runoff suitable for laboratory analysis from larger return storms, while maintaining the sensitivity to collect a representative sample from small events. The criteria for collector performance include: consistency of percent runoff collected under variable conditions; simplicity of installation, serviceability, ease of transport; and cost. A laboratory component evaluated collector consistency; the percent collected should be independent of changes in flow rate (0.09 to 0.15 L/sec) and slope (2%, 5%, and 8%). It was determined that cloth placed in strategic sections of the collector to reduce water surface tension effects on flow stabilized flow and reduced collection variability; it is therefore recommended that cloth be used with this collector design. The 95% confidence interval for percent of introduced water that was collected was 10.83% $\pm$ 0.49%. Laboratory and field results indicate that these collectors are suitable for use under a range

of runoff rates and variable field conditions indicated by non-significant (Pr>F 0.442) flow rate and slope (Pr>F 0.0577) effects. It was determined from field experiences that the collector was relatively simple to transport and install, serviceability was not an issue, and costs were comparable to other collector types.

INTRODUCTION

Erosion and non-point source pollution is a serious threat to production longevity. Topsoil, which is selectively removed by the process of erosion (Hashim et al., 1998) has a high concentration of essential plant nutrients and organic matter (Massey et al., 1953). Erosion removes this invaluable layer; thus bringing subsoils unfavorable for plant root growth closer to the surface (Larson et al., 1983). Not only does erosion degrade the soil resource, but also contributes to water pollution. The most cost-effective method of reducing sediment loss is through conservation tillage practices that leave more residue on the soil surface (Laflen et al., 1978).

There are conflicting results among researchers as to the efficacy of conservation tillage systems. Some studies (Johnson et al., 1979; Laflen et al., 1978) indicate that reduced tillage decreases runoff loss, while others (Ghidey and Alberts, 1998; Mueller et al., 1984) report increased runoff loss through similar systems. Zhao et al. (2001) concluded that tillage systems with a high degree of soil disturbance are more susceptible to higher sediment and sediment-associated nutrient losses. Alternatively, if soluble nutrients are a concern, then those same systems, which allow fertilizer incorporation, are advantageous.

Due to the large variability associated with field plot erosion measurements under natural rainfall, numerous treatment repetitions are needed to estimate runoff and sediment loss for comparison purposes and advancing erosion science (Nearing et al., 1999; Ruttimann et al., 1995; Wendt et al., 1985). To most easily obtain large data sets with numerous plot measurements, collector type selection becomes critical. It is essential to plan for long-term maintenance and ease of operation during collector design considerations (Mutchler, 1963).

The objective of this project was to evaluate a simple, low-profile runoff collector designed to work across large and small runoff events. The collector was designed to obtain representative soil and runoff loss measurements from small field plots with the capacity to store sediment and runoff from larger return storms, while maintaining the sensitivity to collect a representative sample from small events suitable for laboratory analysis. The criteria for collector performance include: consistency of total runoff collected under variable conditions; simplicity of installation, serviceability, ease of transport; and cost.

MATERIALS AND METHODS

Laboratory Study

Collector design

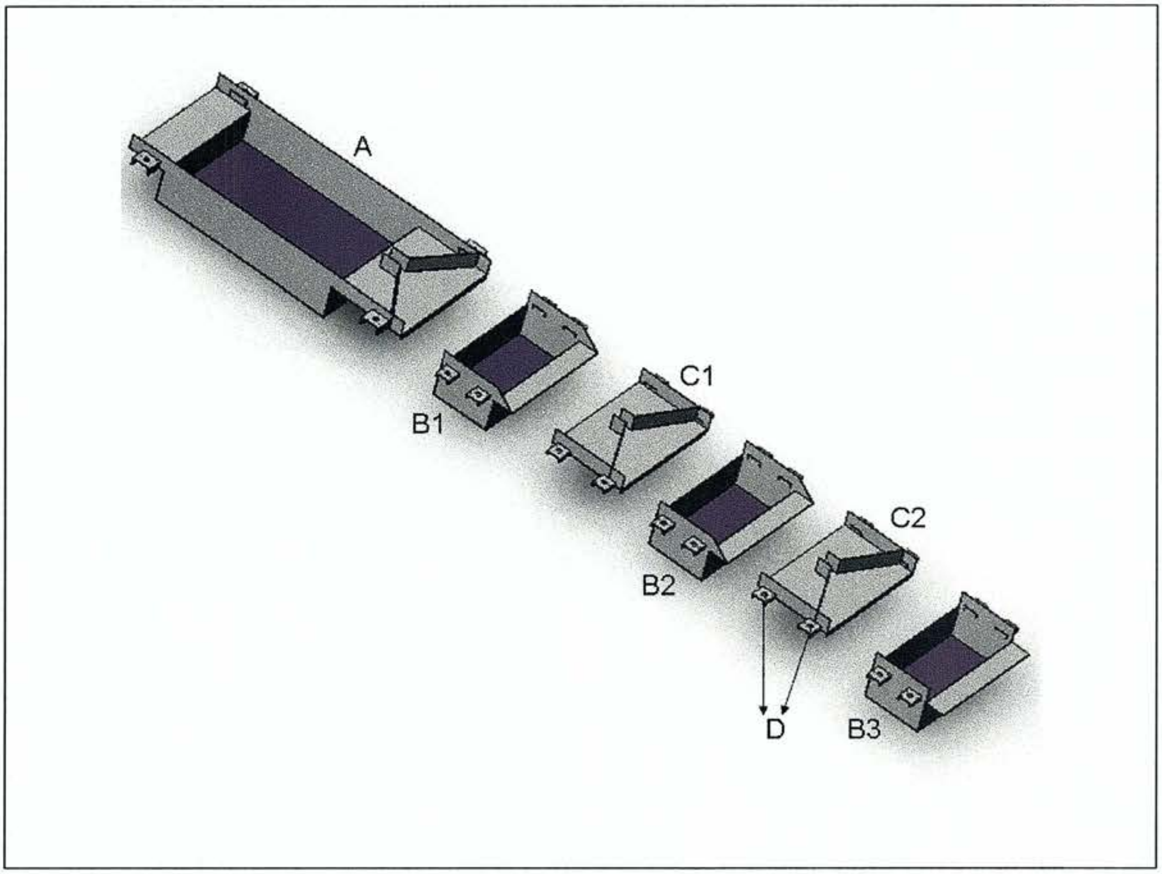
The runoff collector is a modification of the low-impact flow event (LIFE) collectors used in Sheridan et al. (1996) and Franklin et al. (1999). It is approximately 152.4 cm (60 inches) x 40.5 cm (12 inches) x 10 cm (4 inches) and is composed of a series of attachable units which consist of sediment basins and flow splitters. The current design has one large basin/splitter combination unit (See A in Fig. 1) and three additional small basins and two splitters. The units are designed to fit in sequence.

Additional basins and splitters can be added or removed to accommodate plot size and variable size runoff events. The basin function is to reduce incoming runoff velocity, thereby decreasing turbulence, which allows sediment deposition. Design capacity was determined based on a 24-hour, 25-year return storm using estimates of contributing plot area (9.24 m^2 or 100 ft^2) used in field trials. The first basin (See A in Fig. 1) was built sufficiently larger than the succeeding basins because runoff velocity and sediment concentration entering from the plot will be greatest at this position. Runoff accumulates in this pan, with the majority of sediment deposition occurring here. The first basin has a capacity of 15 L (5.25 gallons); the subsequent basins (See B1-3 in Fig. 1) have a capacity of 5 L (1.32 gallon). Once water has filled the first basin to capacity, runoff begins to cascade into the following unit, the splitter (See C1-2 in Fig. 1). Basin size can be modified to fit the design criteria required for plot size and return storm period.

Each splitter is designed to allow a fixed percent of the total runoff to pass through a chute into the following basin, with a large majority of water discarded through holes in the collector bottom. After the first split for this particular collector, approximately 10% of the total plot runoff remains in the basin (B1). This subsample is again subdivided as described previously, with approximately 10% of this subdivided flow being collected with the remaining being discarded. After the second split, approximately 1% of the total plot runoff remains (B2). If the runoff volume is sufficiently large to fill the third basin, the process repeats once more, for a fraction of 0.1% of the total incoming plot runoff being retained in the fourth basin (B3). Additional collector units can be added if expected runoff volumes are greater than that which can be accommodated by three splits.

The collector is constructed from 16-gauge carbon steel as opposed to stainless steel to minimize costs. The average cost of materials and construction was approximately $700 for all components in Fig 1. The collector was primed with an industrial strength primer and a coat of Amber Rustproofing to minimize rusting. Collector leveling is accomplished with the aid of threaded rods, which fit through a section of angle iron welded to the side of each unit (See D in Fig. 1). This brace has a hole to accommodate the threaded rods.

Figure 1. Basin and splitter components.



A: Large basin/splitter combination. B1-B3: small basins C1-2: splitter
D: leveling brace. Cloth location in collector is shown in Figure 2.
Additional photographs of collector field setup are included in Appendix G.

Cloth

To achieve even sheet flow as water exits each basin and flows downslope to a splitter, cloth was used to minimize surface tension effects that can cause water to flow in a non-uniform fashion from the basin onto the splitter. After several failed attempts with leather chamois that bunched after wetting, and cotton muslin that would not wet uniformly, a cellulose chamois cloth, lyocell, performed with success. In addition to its strength and durability, it is known for its highly absorbent properties and environmental friendliness due its ability to biodegrade and is recyclable. According to (Smith) it is the strongest cellulosic fiber when dry and stronger than cotton when wet. This cloth wets immediately and draws water uniformly across the entire cloth and subsequently, across the width of the collector. Cloth was placed at the downslope end of each basin (see Fig.2). Cloth covers the basin wall and splitter floor, a small section extends adjacent to the chute mouth about 2.5 cm (1 in); a section 2.5 cm (1 in) also fits inside the chute.

Figure 2. Cloth location within collector

Laboratory procedure

Collector performance was tested under controlled laboratory conditions to determine if flow rate or slope changes would affect percent of runoff collected. For each trial, a constant volume (20 L) was introduced through a tube placed into the basin center with the flow from the tube projected downward to the basin floor. Water was introduced into basin A to test the first split and collected in basin B1. For the test of the second split (C1), water was introduced into basin B1 and collected in basin B2. The experiment was a completely randomized design with eighteen treatments and four replications performed on three randomly chosen collectors. Treatments were a factorial combination with three slopes (2%, 5%, and 8%), three flow rates (0.09, 0.1, and 0.15 L/sec) and cloth (presence or absence). Flow rates are equivalent to that expected from field plots used to test collectors at the 1-hour, 25-year; 30-min, 5-year; and 15-min, 5-year return storms respectively. These are approximate return storm estimates based on the rational method (Schwab et al., 1993). Following addition of 20 L of water to the basin in front of the splitter being tested, the collected water was removed, poured into a graduated cylinder and volume recorded.

Field Study

The field proportion of this study was conducted within the Upper Mississippi River Valley at the University of Wisconsin, Lancaster Agricultural Research Station (lat. 42°50' N; long. 90°47'; elev. 325 m) on a moderately well drained Rozetta silt loam (fine silty, mixed, superactive, mesic Typic Hapludalf) (N.R.C.S., 2006). Mean annual temperature is 7.7°C. The average annual precipitation of the area is 762 mm, of which 508 mm falls during the growing season.

Tillage

Tillage systems were initiated in October 2003 in a two hectare (five acre) contour strip (Wolkowski et al., 2006). The field containing the plots was previously in corn and is 30.48 m (100 ft.) wide and has an average slope of 8%. The east half of the field was planted to soybeans and the west half to corn in 2003. In the fall of 2003 tillage treatments were (fall chisel/spring field cultivator, strip-till) installed in the soybean residue along the length of the strip. Each tillage plot was 15.2 m (50 ft.) long and 4.56 m (15 ft) alleys separated the individual tillage treatments. The same tillage treatment existed across the full width of the strip. The chisel system employed a fall twisted shank plow, followed by a single pass with a combination field cultivator in the spring. Strip-tillage was conducted in the fall with a four-row tool that features finger coulters, a ripple coulter, and a mole knife that runs 17.78 – 20.32 cm (7-8 inches) deep, followed by closing disks that form a ridge 10.16 – 15.24 cm (4-6 inches) high. The width of each tilled segment was approximately 25.4 cm (10 in).

A full season corn hybrid (DeKalb DKC50-20, RM 100 days) was planted on 5 May 2004 in 76.2 m (30 inch) rows at a maximum population of 86,600 seeds/ha (35,000 seeds/acre). To simplify weed control a Roundup Ready hybrid was used. Residue measurements were taken in late May using the line transect method showed that chiseled treatments had approximately 54% and 43% cover and strip-till had 59% and 65% in 2004 and 2005, respectively. The chisel plow used for the 2004 season was equipped with sweeps as opposed to twisted shovels used for the 2005 season.

Installation

Runoff collectors, similar to those in Sheridan et al (1996) and (Franklin et al., 2001) were installed into corn in one chiseled and one strip-till plot on 10 May 2004. The plot area was 1.6-m (5 ft.) by 7-m (20 ft.) and was isolated from the surrounding plot area with sheet metal borders driven into the ground. The borders eliminated water runoff and run-on to the test plot. A metal apron spanning the plot width was installed directly in front of the collector; the apron received field runoff and directed it into the collector. A tarp was placed over the collector to prevent raindrop splash into the collector body. Wire mesh screen cloth was placed in front of the apron to intercept residue that may move with flowing water and enter the collectors. Each collector basin was leveled independently. Water was used as a leveling tool – each collector unit was leveled such that even sheet flow downslope within the collector was observed. All collectors were not necessarily set with a common within collector slope. Soil was excavated at the plot end to accommodate collector depth such that the collector 'floor' was at an elevation slightly lower than the plot soil surface. To enhance stability, threaded rods were placed to support each unit on timbers driven into the ground.

The new runoff collectors, those described in detail in this paper, were installed on 10 June 2004. Since only two collectors were available, we replaced one low-impact flow event (LIFE) collector from each chisel and strip-till plot with the new design. On 10 May 2005, four runoff collectors were installed in four plots – two chiseled and two strip-till.

Calibration

Field calibration was performed several times throughout the growing season. A known volume of water was introduced into each collector section at different inflow rates. The percent of the introduced water that was collected in the subsequent basin was used as the calibration factor for that collector section. The percentage that was collected during runoff events was assumed to equal the calibration factor obtained during field calibration. The calibration factors ranged from 5.6% to 15.9%, depending on the collector.

Field servicing and sampling

In the field plots, water and sediment sampling was done after each runoff event from May to September in 2004 and 2005. Rain gauges were located about 800 M (0.5 mile) from the field. A hand-held vacuum pump was used initially to remove water and sediment from the basins to 1-L plastic bottles. Due to large runoff events in 2004, this proved to be a time-consuming chore, which led to the use of a 12-V battery operated sprayer pump to remove water from the basins. Collectors were inspected during sampling and calibration trials for residue that may have entered the collector and interfered with collector performance, as well as leveling changes. Any obstructions or materials that may have interfered with performance were removed, and leveling was conducted as needed.

Sampling technique

After removal of runoff and sediment from the collector, 1 L bottles were transported to the University of Wisconsin in Madison for analysis. To obtain a representative sample of water and sediment, simultaneous withdrawal of sediment and water samples from different depths immediately follows stirring. Glass tubes of different lengths were joined to a common plastic tube that was attached to a vacuum flask. Samples were stirred and the glass tubes were inserted immediately. The vacuum was started and the glass tubes positioned at different depths withdrew water and sediment. The same apparatus was used by Eleki (2003).

Runoff volume and sediment load calculation

For the total sediment load calculation the samples from the sediment basins were used. It was assumed the subsample concentration obtained from the method described above and the field sample was equal. The concentration and the amount of soil in the field sample were calculated from the subsample sediment determination. For the total runoff calculations, water samples were used. Estimates of total water runoff entering the collector were based on the results of the field calibration and the quantities of water collected in the different collector sections. In 2005, a ruler was used to measure the depth of standing water in the basins. One measurement was taken at the top (upslope) of the basin and one measurement at the bottom (downslope) of the basin. The following equation (area of a trapezoid) was used to convert depth measurements to volume of water in each basin:

$$\text{Upslope measurement (cm)} + \text{downslope measurement (cm)}$$
$$\text{*basin length (cm)}/2 = \text{X cm}^2$$

$$\text{X cm}^2 * \text{basin width (cm)} = \text{Y cm}^3/1000 \text{ cm}^3 = \text{Z liters}$$

Runoff water was removed with the pump described previously and sediment was removed and taken to the University of Wisconsin for lab analysis.

Analysis of variance was performed with field data to determine tillage treatment effects on runoff and sediment loss for the 2005 data. The design was treated as a randomized complete block. Treatment differences were regarded as significant at a probability level of 0.05. Statistical analysis was comprised of the analysis of variance, Fischer's protected LSD, t-tests and p-diff tests.

RESULTS AND DISCUSSION

Laboratory Results

Runoff percent is calculated by: X L captured/20 L *100 = percent collected, where 20 L is the initial volume introduced into the collector. Data averages are presented in Table 1. Raw data collected during laboratory analysis is presented in Appendix A.

Un-summarized statistical analysis is presented in Appendix B. The ANOVA table for laboratory runoff collection is given in Table 2. Collector is represented by 'coll' and flow rate by 'flow'.

Table 1. Average percent and volume of water collected in the laboratory under different slopes, flow rates and cloth presence or absence averaged over collector.

Flow Rate (L/sec)	Slope (%)		Material: Presence Percent	Presence Volume (mL)	Absence Percent	Absence Volume (mL)
	2		10.3	2070.41	15.5	3117.29
0.157	5		11.87	2365.62	12.96	2557.29
	8		12.02	2386.66	12.61	2523.54
		Mean	**11.39**	2274.23	**13.69**	2732.7
	2		10.0	1959.58	12.3	2461.25
0.101	5		10.63	2141.25	11.64	2328.33
	8		11.33	2266.08	11.36	2273.95
		Mean	**10.65**	2122.3	**11.76**	2354.51
	2		9.8	1946.66	14.7	2975.41
0.096	5		10.19	2038.33	11.50	2228.26
	8		11.18	2236.25	15.05	3007.39
		Mean	**10.39**	2073.75	**13.75**	2737.02

Cloth Effects

There are multiple significant effects shown in Table 2, but of particular interest is the effect of cloth. To address this effect, we calculated the 95% confidence interval associated with cloth and no cloth trials. When present, the confidence interval was 10.34% to 11.31% with a mean of 10.83%. The absence of cloth yielded a wider range; the confidence interval being 12.52% to 13.58%, with a mean of 13.05%. The data indicate that cloth stabilized flow, reduced collection variability, and brought the measured mean closer to the theoretically correct percent collected (discussed later).

Table 2. Statistical summary for laboratory runoff

Source	DF	Type III SS	Mean Square	F Value	Pr>F
Coll	2	14.667	7.333	0.35	0.732
Rep(Coll)	3	63.453	21.151	1.96	0.120
Cloth	1	500.725	500.725	46.34	<0.0001
Coll*cloth	2	32.782	16.391	1.52	0.220
Flow	2	92.541	46.270	4.28	0.014
Coll*flow	4	306.957	76.739	7.10	<0.0001
Cloth*flow	2	86.962	43.481	4.02	0.018
Coll*cloth*flow	4	88.498	22.124	2.05	0.087
Slope	2	71.902	35.951	3.33	0.037
Coll*slope	4	122.228	30.557	2.83	0.024
Cloth*slope	2	215.960	107.980	9.99	<0.0001
Coll*cloth*slope	4	43.109	10.777	1.00	0.408
Flow*slope	4	99.715	24.928	2.31	0.057
Coll*flow*slope	8	57.828	7.228	0.67	0.718
Cloth*flow*slope	4	79.806	19.951	1.85	0.119
Coll*cloth*flow*slope	8	67.596	8.449	0.78	0.618
Basin	2	4.920	4.920	0.46	0.500
Coll*basin	2	88.656	44.328	4.10	0.017
Cloth*basin	1	0.091	0.091	0.01	0.926
Coll*cloth*basin	2	7.981	3.990	0.37	0.691
Flow*basin	2	340.294	170.147	15.75	<0.0001

Most means in Table 1. were numerically greater than 10%; the measured mean from the laboratory trials was compared with the theoretical mean. To determine the theoretical mean, collector body width and chute width were measured; in theory the percent collected should be equivalent to the ratio of the splitter chute width to collector width area, and therefore, a theoretical fixed percent of runoff should be collected. It was found that the theoretical percent collected should range from 10.56% to 11% depending on collector (Appendix D). For example, if even sheet flow was achieved, the chute should intercept 10.56% of the total flow for collector C. T-tests were performed to determine if actual percent collected was significantly different from theoretical percent. Results are given in Table 3. See Appendix E for statistical analysis.

Table 3. T-tests (Pr > |t|)comparing theoretical collection percent vs. that observed for cloth present (Y) or not present (N)

Basin two (B1 in Fig. 1)					
		Measured		T-test	
	Theoretical	Y	N	Y	N
Collector C	10.56	10.14	12.12	0.41	0.001*
Collector D	10.56	11.19	13.3	0.13	0.0005*
Collector F	10.82	11.37	14.3	0.4	<0.0001*
Basin three (B2 in Fig. 2)					
		Measured		T-test	
	Theoretical	Y	N	Y	N
Collector C	10.97	9.37	11.89	0.006*	0.137
Collector D	11	10.43	11.47	0.41	0.53
Collector F	10.56	12.4	15.1	0.007*	<0.0001*

Cloth allowed more precise collection for basin two trials relative to the theoretical collection target of each collector. When cloth was present, the means of all three collectors (C, D, and F) at the basin two (B2) position were not significantly different from the theoretical estimate; however, without cloth they were significantly different from the theoretical target.

Results at the basin three position varied between collectors. Interestingly, the measured mean for collector C was significantly different from the theoretical mean with cloth; however, without cloth, the measured mean was not significantly different. The reason for this is unknown. Both measured means (with and without cloth) for collector D were not significantly different from the theoretical target. Conversely both measured means (with and without cloth) were significantly different from the theoretical percent for collector F. Conflicting results could be an artifact of introducing water into the middle of the smaller basin (B1), creating more turbulence and uneven flow than that observed from the water introduction into the larger basin (A). This may have caused preferential flow down the middle and subsequently through the chute and into the next basin. S. Sombatpanit et al. (1990) anticipated that the attainment of the expected split ratio of a double-split divisor would not be obtained due to manufacturing errors and the hydraulic properties of water flowing through small channels of different lengths. They recommended field calibration to account for differences.

A noticeable decrease in the data spread occurred with cloth present; it allowed greater collection consistency because it disrupted the effect of water surface tension. Consistency is critical for collectors under field conditions. It was observed in trials without cloth that as basins filled with runoff, the water elevation would exceed the exit elevation of the following unit due to surface tension. The tension broke at a random location and water cascaded unevenly in many instances through the next splitter. Several trials were observed in the laboratory where all water ran through the discard holes and none through the splitter chute. This would lead to the erroneous assumption that no runoff had occurred if left unattended in a field plot. The effect of cloth caused the collector to perform differently; two tests (confidence interval and t-tests) were performed to determine if the observed differences were significant. Both have indicated that the collector performs more consistently with cloth. Therefore, the remaining discussion will be on variability with cloth present and its interactions with other factors. The ANOVA table for laboratory runoff collection with cloth only trials is presented in Table 4.

Cloth Treatment Analysis

Table 4. Statistical summary for laboratory runoff: cloth treatments only

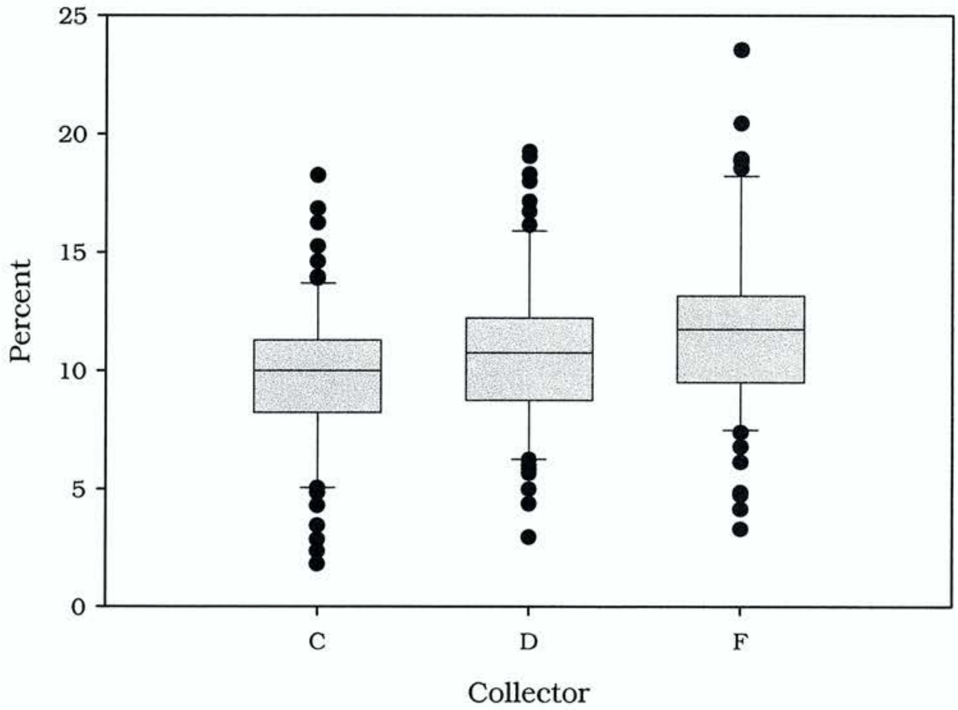
Source	DF	Type III SS	Mean Square	F Value	Pr>F
Coll	2	6.34	3.17	0.15	0.86
Rep(Coll)	3	64.3	21.4	1.94	0.125
Flow	2	18.12	9.06	0.82	0.442
Coll*flow	4	75.9	18.97	1.72	0.149
Slope	2	64.25	32.13	2.91	0.057
Coll*slope	4	122.12	30.53	2.76	0.029
Flow*slope	4	7.19	1.79	0.16	0.956
Coll*flow*slope	8	43.95	5.49	0.5	0.857
Basin	1	1.94	1.94	0.18	0.675
Coll*basin	2	35.5	17.77	1.61	0.203
Basin*flow	2	374.8	187.44	16.96	<0.0001
Coll*basin*Flow	4	16.23	4.05	0.37	0.831
Basin*slope	2	4.12	2.06	0.19	0.829
Coll*basin*slope	4	13.73	3.43	0.31	0.87
Basin*flow*slope	4	10.9	2.73	0.25	0.91
Coll*basin*flow*slope	8	43.2	5.4	0.49	0.862

Flow Rate

The critical component is the effect of flow rate. In the field it is possible to install collectors at a fixed slope; however, we can not control the flow rate under natural rainfall conditions. Therefore, it is necessary that the percent collected must be consistently maintained across a range of flow rates. Flow rate (flow in Table 4) is no longer significant when analysis was performed for data obtained only with cloth present in the collectors. The lack of a significant flow effect indicates that we can use these collectors under a range of runoff rates and variable field conditions. There was, however, a significant flow*basin interaction that will be discussed later.

Collector

Figure 3. Boxplot of percent runoff captured by each collector.

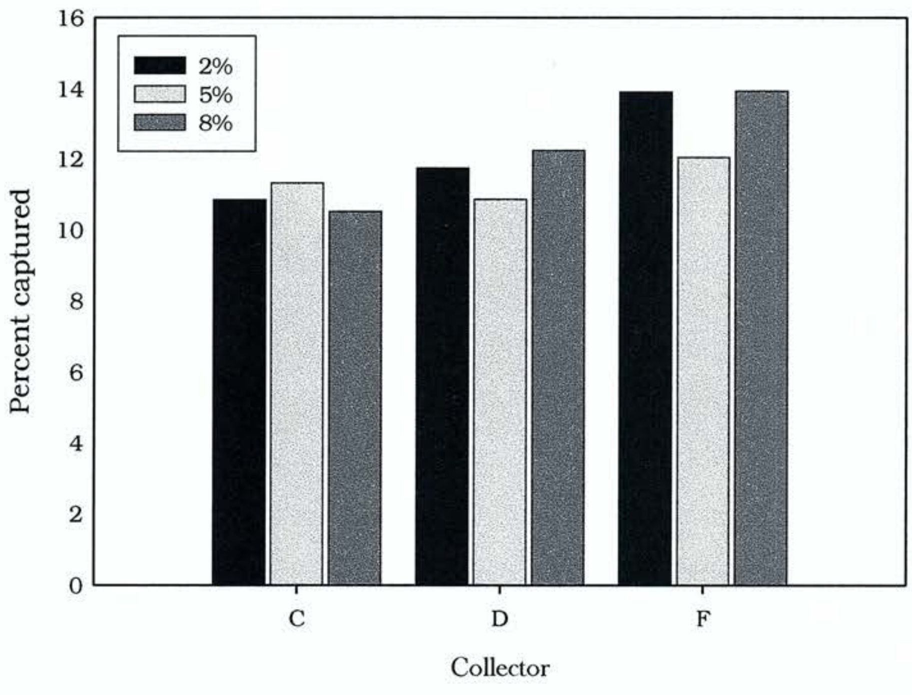


The data variability associated each collector is displayed in Figure 3. It appears that the median of the collectors are not widespread, however, collector F has more distant outliers. The variation in collectors is attributed to the fabrication by different people at various times, although from the same design pattern. Collector F collected more runoff than collector C and D due to small but apparently significant manufacturing differences. It was observed that collector F units did not fit together as well as other collectors. In addition, discarded water from A (first basin) ran under C1 (first splitter) and into the following basin (B1). To correct for this in the future, more stringent manufacturing criteria must be enforced. It is important to note that the variability (numerically a 2% spread) between collector means relative to the variability introduced by field conditions render variability associated with these collectors marginally important.

Wendt et al. (1985) declared that a portion of the unexplained variability between plots was due to collector bias. However, they concluded that the measurement error should be systematic and not a dominant source of unexplained variability. Many studies (Nearing et al., 1999; Ruttimann et al., 1995; Wendt et al., 1985) report large variability among replicated field plots. Although error introduced by the collector is negligible to that introduced by natural variability, it is recommended that field calibration be performed to test for non-uniformities between collectors.

Collector by slope interaction

Figure 4. Collector by slope interaction

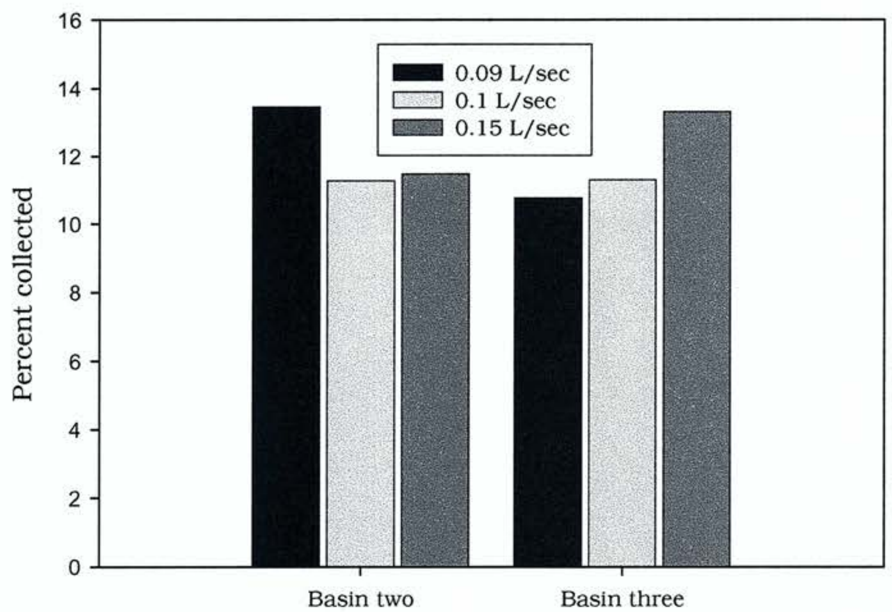


There was a significant collector by slope interaction, but no trends are observed in Figure 4 between slopes and collectors. Collector F collected the greatest percent at every slope. According to the p-diff results (Appendix C) there are no significant differences between any collectors at the 5%

slope. There were significant differences between collector C and F at the 2% and 8% slopes. The amount collected was sensitive to slope changes, but this is not important as collectors can be set and maintained at given slope for the duration of the field trial. It does, nonetheless, indicate that care must be taken during installation to establish and maintain slope consistency among collectors.

Basin by flow interaction

Figure 5. Basin by flow interaction



It is apparent from figure 5, that there is a direct response of percent collected to higher flow rates in basin three. According to p-diff results (Appendix C) there is a significant difference between 0.09 L/sec and 0.15 L/sec for basin two. Basin two and three were significantly different at the 0.09 and 0.15 L/sec flow rates. All three flow rates were significantly different at the basin three position. These results were anticipated due to the differences in size between basin two and three. Basin two, being the larger of the two, has sufficient area to allow water velocity to slow, thereby permitting more even sheet flow upon exiting the basin. Basin three is much smaller – water was introduced via a tube into the center of the basin and consequently created turbulent conditions preventing the even sheet flow required for the collector to perform adequately. The significant difference appears to be an artifact of the method of water introduction into the collector during laboratory trials.

2004 field results

Table 5. 2004 growing season runoff and sediment delivery for six runoff events in two tillage treatments, chisel (CH) and strip-till (ST). Precipitation is cumulative over time periods between sampling dates. If time between field sampling is greater than seven days, then it reflects only the precipitation for seven days prior to sampling date. Averages calculated from two replications per treatment.

Sampling Date 2004	Precip (mm)	Average Sediment Delivery (kg/ha)		Average Runoff (mm)	
		CH	**ST**	**CH**	**ST**
May 14	55.12	553.86	30.69	0.51	0.77
May 21	12.7	589.61	0	0.425	1.05
May 24	124.46	9659.58	447.11	>7.5	12.06
June 1	77.47	1370.79	88.05	8.8	1.96
June 17	103.63	1790.39	7.29	78.24	96.84
July 12	28.96	633.21	20.57	29.94	11.82
August 4	35.56	499.2	0	2.77	1.87
Total	437.9	15096.64	593.71	120.68	126.37

Statistical analysis was not performed for 2004 field data due to lack of suitable replication. Therefore relative runoff and sediment loss averages will be discussed. Four modified LIFE (Franklin et al, 2001) collectors were in place during May and two remained throughout the season duration after replacement with the new design. LIFE collector overflows occurred on several events throughout the season (May 21, 24 and August 4) where the

100X split was overwhelmed. This indicates a lack of adequate design and storage for the collected runoff sample. In 2004 strip-till consistently had a smaller sediment load than chiseled treatments. This may be partly due to the slightly greater residue (5%) cover of strip-till treatments relative to chiseled treatments. According to Laflen et al. (1978) 78% to 89% of the variance in erosion among tillage systems was accounted for by residue cover. However, strip-till experienced slightly greater runoff than chiseled treatments in four of seven events and had a slightly higher overall season loss. This is not unrealistic as others (Mueller et al., 1984) have reported similar results with conservation tillage trials. On July 12, the runoff reported for chiseled treatments exceeds the precipitation amount recorded. The information does not correspond, likely because the rain gauges were located one-half mile from the plot location and large spatial variability is well-known for summer storms in the Central U.S.

2005 field results

The analysis of variance was performed for 2005 results. There was no significant difference (pr>F 0.3153) between the two treatments (See Appendix F). With only two replications, it is difficult to distinguish between treatments relative to sediment and runoff loss. The variability associated with field plot measurements (Nearing et al., 1999; Wendt et al., 1985) adds an additional challenge due to large natural variability which makes it difficult to differentiate between treatments without several replications.

Even though there were no significant differences between treatments, relationships that address collector performance will be discussed. 2005 growing season data is presented in Table 6. In 2005 strip-till had a greater sediment load for two events (July 25, Aug. 19). When averaged over the season, strip-till experienced less sediment loss than chisel, consistent with

2004. Strip-till plots experienced less runoff than chisel over the season, opposite of the 2004 growing season. Only one event on July 26 gave strip-till slightly greater runoff. The difference in residue was statistically different between strip-till and chiseled treatments in 2005. Less runoff occurred from strip-till plots; this was an anticipated result due to increased surface cover of strip-till treatments.

Table 6. 2005 growing season runoff and sediment delivery results for six runoff events in two treatments.

Sampling Date 2005	Precipitation (mm)	Avg. Sediment Delivery (kg/ha)		Avg. Runoff Delivery (mm)	
		CH	**ST**	**CH**	**ST**
June 6	24.9	103.1	44.89	1.38	0.98
June 27	127	184.43	29.17	4.61	2.86
July 25	104.9	224.7	261.7	16.79	16.38
July 26	33	2.64	0	0.33	0.41
August 19	85.59	2.06	31.87	13.37	11.8
Sept 19	42.9	35.61	7.07	4.14	0.22
Total	418.29	552.54	374.7	40.62	32.65

Averages calculated from two replications per treatment.

Sediment delivery and runoff loss

The measured soil delivery was low with the exception of chiseled plots in 2004, which was 15,096 kg/ha (6.7 tons/acre); ST lost 594 kg/ha (>1 ton/ac). In 2005, CH and ST lost 552.54 kg/ha and 374.7 kg/ha (<1 ton/ac each) respectively. Relatively low sediment losses were anticipated due to the short slope length 6 m (20 ft) of the plots. Runoff plots were only about 1/3 the length of USLE standard runoff plots (Wischmeier and Smith, 1978 as cited by Eleki (2003). Soil loss can be significantly reduced with a reduction in slope length. Our results are consistent with previous research results in the same region for plots of equal size. In that study, Eleki (2003) reported <1 ton/ac (~300 kg/ha) sediment delivery for nine rainfall events in conventionally tilled corn and no-till corn with cover crop treatments; low results were attributed to soil conditions and rainfall characteristics not conducive to large sediment loss. Sheridan et al. (1996) also reported low sediment concentration; most of the minimal losses can be attributed to the riparian buffer system used in the study and low-gradient slopes and low soil erodibility in the study. Runoff losses for chiseled treatments were 27% and ~10% of estimated rainfall, while strip-till losses were 28% and ~8% for 2004 and 2005, respectively. It is also important to note that both treatments were planted on the contour. This is known to reduce sediment and runoff delivery. If, however, the plots were oriented parallel to the slope, the likelihood of greater sediment and runoff loss with strip-till treatments would increase due to the preferential flow down the bare row zone.

Although there were no detected significant differences between strip-till and chiseled treatments, trends suggest that strip-till may result in lower sediment loss than chisel when planted on the contour. This agrees with other studies (Johnson et al., 1979; Laflen et al., 1978) with tillage system comparisons. Measured losses followed anticipated differences relative to surface cover between chiseled and strip-till plots.

Collector performance

Field results obtained with these collectors were not unexpected. Based on laboratory consistency and reasonable field measurements it can be said that these collectors performed satisfactorily. The measured data fits the runoff and soil loss trends seen in literature where comparisons between tillage systems are made. The collector has met the design criteria of maintaining consistency of total runoff collected under variable conditions; simplicity of installation, use, and transport; and minimal expense.

Design Recommendations

To ease field installation time requirements, a metal frame could be constructed in the laboratory which would accommodate the collector. The separate units could be attached to the frame and leveled in the laboratory. The frame would prevent accidental movement of units during field sampling and subsequent changes in level. To avoid excessive soil excavation to accommodate collector unit depth, it is advised that PVC pipe be used to channel runoff water and sediment from the plot outlet down-slope to the collector. If the natural slope of the land permits, this transfer might not need to be longer than a few meters.

Suggested research

Sediment analysis must be performed in the laboratory to determine the calibration factor for sediment that does not settle out of the first basin and that moves through the collector with runoff water. Sediment loss estimates were based on the same calibration factor used for runoff water. Fine sediment particles that do not readily settle in the first basin should move evenly-distributed with the flowing water and be partitioned similarly to the water moving through the collector.

In addition, a protocol needs to be established for water quality sampling. The samples from the different basins must be recombined in a manner that will allow a representative sample to be obtained for the water quality parameter in question.

CONCLUSIONS

The collector performance as indicated by laboratory and field analysis show that the collector performed satisfactorily. Total runoff collected under variable conditions was consistent; installation was straightforward, serviceability and transportation were not an issue, and costs were relatively inexpensive. The laboratory data indicate that cloth Cloth stabilized flow and reduced collection variability and percent runoff collected. A noticeable decrease in the data spread occurred with cloth present; it allowed us to collect with greater consistency because it disrupted the negative effect of water surface tension. The lack of a significant flow effect indicates that we can use these collectors under a range of runoff rates and variable field conditions. Although error introduced by the collector is negligible to that introduced by natural variability, it is recommended that field calibration be performed. In addition, care must be taken during installation to establish and maintain slope consistency among collectors. There was a significant basin by flow interaction, but this is attributed to the method of water introduction during laboratory trials. The measured soil delivery in field trials was low with the exception of chiseled plots in 2004, however, these relatively low losses were anticipated due to the short slope length 6 m (20 ft) of the plots. Although there were no detected significant differences between strip-till and chiseled treatments, it appears based on averages that strip-till on the contour may result in lower sediment loss.

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APPENDIX A. RAW LABORATORY DATA

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
C	1	13	Y	8	0.09	2	1010	5.05
C	1	13	Y	8	0.09	3	860	4.3
C	1	12	N	5	0.15	2	3740	18.7
C	1	12	N	5	0.15	3	3170	15.85
C	1	14	N	8	0.09	2	2600	13
C	1	14	N	8	0.09	3	1710	8.55
C	1	18	N	8	0.15	2	2290	11.45
C	1	18	N	8	0.15	3	3595	17.975
C	1	6	N	2	0.15	2	2340	11.7
C	1	6	N	2	0.15	3	4315	21.575
C	1	7	Y	5	0.09	2	3250	16.25
C	1	7	Y	5	0.09	3	690	3.45
C	1	9	Y	5	0.1	2	2500	12.5
C	1	9	Y	5	0.1	3	2550	12.75
C	1	11	Y	5	0.15	2	3650	18.25
C	1	11	Y	5	0.15	3	3050	15.25
C	1	3	Y	2	0.1	2	2190	10.95
C	1	3	Y	2	0.1	3	1930	9.65
C	1	4	N	2	0.1	2	2390	11.95
C	1	4	N	2	0.1	3	2050	10.25
C	1	16	N	8	0.1	2	2065	10.325
C	1	16	N	8	0.1	3	1980	9.9
C	1	10	N	5	0.1	2	2175	10.875
C	1	10	N	5	0.1	3	2580	12.9
C	1	5	Y	2	0.15	2	1430	7.15
C	1	5	Y	2	0.15	3	1610	8.05
C	1	8	N	5	0.09	2	1350	6.75
C	1	8	N	5	0.09	3	2900	14.5
C	1	17	Y	8	0.15	2	2130	10.65
C	1	17	Y	8	0.15	3	2080	10.4
C	1	1	Y	2	0.09	2	1760	8.8
C	1	1	Y	2	0.09	3	360	1.8
C	1	15	Y	8	0.1	2	2225	11.125
C	1	15	Y	8	0.1	3	1890	9.45
C	1	2	N	2	0.09	2	2430	12.15
C	1	2	N	2	0.09	3	2320	11.6

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
C	2	3	Y	2	0.1	2	2320	11.6
C	2	3	Y	2	0.1	3	1575	7.875
C	2	15	Y	8	0.1	2	2380	11.9
C	2	15	Y	8	0.1	3	1380	6.9
C	2	13	Y	8	0.09	2	2920	14.6
C	2	13	Y	8	0.09	3	2150	10.75
C	2	7	Y	5	0.09	2	2790	13.95
C	2	7	Y	5	0.09	3	1680	8.4
C	2	5	Y	2	0.15	2	570	2.85
C	2	5	Y	2	0.15	3	2260	11.3
C	2	9	Y	5	0.1	2	2180	10.9
C	2	9	Y	5	0.1	3	2530	12.65
C	2	4	N	2	0.1	2	2550	12.75
C	2	4	N	2	0.1	3	2750	13.75
C	2	18	N	8	0.15	2	2580	12.9
C	2	18	N	8	0.15	3	1590	7.95
C	2	17	Y	8	0.15	2	2120	10.6
C	2	17	Y	8	0.15	3	2250	11.25
C	2	1	Y	2	0.09	2	2640	13.2
C	2	1	Y	2	0.09	3	1670	8.35
C	2	16	N	8	0.1	2	2430	12.15
C	2	16	N	8	0.1	3	1400	7
C	2	12	N	5	0.15	2	2010	10.05
C	2	12	N	5	0.15	3	2720	13.6
C	2	2	N	2	0.09	2	3360	16.8
C	2	2	N	2	0.09	3	3970	19.85
C	2	10	N	5	0.1	2	2240	11.2
C	2	10	N	5	0.1	3	1920	9.6
C	2	11	Y	5	0.15	2	1960	9.8
C	2	11	Y	5	0.15	3	2000	10
C	2	8	N	5	0.09	2	1890	9.45
C	2	8	N	5	0.09	3	1760	8.8
C	2	6	N	2	0.15	2	3125	15.625
C	2	6	N	2	0.15	3	2290	11.45
C	2	14	N	8	0.09	2	2630	13.15
C	2	14	N	8	0.09	3	2140	10.7

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
C	3	16	N	8	0.1	2	2075	10.375
C	3	16	N	8	0.1	3	1870	9.35
C	3	1	Y	2	0.09	2	1390	6.95
C	3	1	Y	2	0.09	3	1680	8.4
C	3	13	Y	8	0.09	2	1860	9.3
C	3	13	Y	8	0.09	3	2000	10
C	3	2	N	2	0.09	2	3160	15.8
C	3	2	N	2	0.09	3	2120	10.6
C	3	9	Y	5	0.1	2	2080	10.4
C	3	9	Y	5	0.1	3	2250	11.25
C	3	10	N	5	0.1	2	2250	11.25
C	3	10	N	5	0.1	3	1850	9.25
C	3	8	N	5	0.09	2	2610	13.05
C	3	8	N	5	0.09	3	2520	12.6
C	3	15	Y	8	0.1	2	2320	11.6
C	3	15	Y	8	0.1	3	1710	8.55
C	3	4	N	2	0.1	2	1120	5.6
C	3	4	N	2	0.1	3	2660	13.3
C	3	12	N	5	0.15	2	1860	9.3
C	3	12	N	5	0.15	3	2060	10.3
C	3	3	Y	2	0.1	2	1080	5.4
C	3	3	Y	2	0.1	3	1400	7
C	3	18	N	8	0.15	2	2570	12.85
C	3	18	N	8	0.15	3	2110	10.55
C	3	17	Y	8	0.15	2	2000	10
C	3	17	Y	8	0.15	3	2650	13.25
C	3	6	N	2	0.15	2	2520	12.6
C	3	6	N	2	0.15	3	3020	15.1
C	3	14	N	8	0.09	2	2160	10.8
C	3	14	N	8	0.09	3	2380	11.9
C	3	5	Y	2	0.15	2	1640	8.2
C	3	5	Y	2	0.15	3	2270	11.35
C	3	11	Y	5	0.15	2	2020	10.1
C	3	11	Y	5	0.15	3	3370	16.85
C	3	7	Y	5	0.09	2	2220	11.1
C	3	7	Y	5	0.09	3	1850	9.25

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
C	4	5	Y	2	0.15	2	1970	9.85
C	4	5	Y	2	0.15	3	1330	6.65
C	4	10	N	5	0.1	2	2040	10.2
C	4	10	N	5	0.1	3	2120	10.6
C	4	9	Y	5	0.1	2	1390	6.95
C	4	9	Y	5	0.1	3	2070	10.35
C	4	15	Y	8	0.1	2	2060	10.3
C	4	15	Y	8	0.1	3	1850	9.25
C	4	2	N	2	0.09	2	3575	17.875
C	4	2	N	2	0.09	3	2000	10
C	4	6	N	2	0.15	2	2850	14.25
C	4	6	N	2	0.15	3	3680	18.4
C	4	3	Y	2	0.1	2	1920	9.6
C	4	3	Y	2	0.1	3	1850	9.25
C	4	7	Y	5	0.09	2	1020	5.1
C	4	7	Y	5	0.09	3	2150	10.75
C	4	8	N	5	0.09	2	3130	15.65
C	4	8	N	5	0.09	3	580	2.9
C	4	16	N	8	0.1	2	2230	11.15
C	4	16	N	8	0.1	3	2310	11.55
C	4	14	N	8	0.09	2	1890	9.45
C	4	14	N	8	0.09	3	2370	11.85
C	4	12	N	5	0.15	2	2280	11.4
C	4	12	N	5	0.15	3	2590	12.95
C	4	1	Y	2	0.09	2	1820	9.1
C	4	1	Y	2	0.09	3	470	2.35
C	4	18	N	8	0.15	2	2310	11.55
C	4	18	N	8	0.15	3	2460	12.3
C	4	11	Y	5	0.15	2	2250	11.25
C	4	11	Y	5	0.15	3	2775	13.875
C	4	4	N	2	0.1	2	2465	12.325
C	4	4	N	2	0.1	3	1800	9
C	4	13	Y	8	0.09	2	2020	10.1
C	4	13	Y	8	0.09	3	970	4.85
C	4	17	Y	8	0.15	2	1890	9.45
C	4	17	Y	8	0.15	3	2340	11.7

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
D	1	14	N	8	0.09	2	3080	15.4
D	1	14	N	8	0.09	3	3710	18.55
D	1	17	Y	8	0.15	2	1845	9.225
D	1	17	Y	8	0.15	3	2250	11.25
D	1	11	Y	5	0.15	2	2220	11.1
D	1	11	Y	5	0.15	3	2180	10.9
D	1	8	N	5	0.09	2	0	0
D	1	8	N	5	0.09	3	0	0
D	1	9	Y	5	0.1	2	2000	10
D	1	9	Y	5	0.1	3	1740	8.7
D	1	16	N	8	0.1	2	2645	13.225
D	1	16	N	8	0.1	3	2005	10.025
D	1	1	Y	2	0.09	2	3065	15.325
D	1	1	Y	2	0.09	3	590	2.95
D	1	15	Y	8	0.1	2	2891	14.455
D	1	15	Y	8	0.1	3	1840	9.2
D	1	18	N	8	0.15	2	2630	13.15
D	1	18	N	8	0.15	3	2455	12.275
D	1	4	N	2	0.1	2	3200	16
D	1	4	N	2	0.1	3	2000	10
D	1	13	Y	8	0.09	2	3660	18.3
D	1	13	Y	8	0.09	3	875	4.375
D	1	12	N	5	0.15	2	2340	11.7
D	1	12	N	5	0.15	3	3720	18.6
D	1	6	N	2	0.15	2	2945	14.725
D	1	6	N	2	0.15	3	3740	18.7
D	1	3	Y	2	0.1	2	2310	11.55
D	1	3	Y	2	0.1	3	1135	5.675
D	1	10	N	5	0.1	2	2475	12.375
D	1	10	N	5	0.1	3	2515	12.575
D	1	2	N	2	0.09	2	950	4.75
D	1	2	N	2	0.09	3	0	0
D	1	5	Y	2	0.15	2	2335	11.675
D	1	5	Y	2	0.15	3	2950	14.75
D	1	7	Y	5	0.09	2	3345	16.725
D	1	7	Y	5	0.09	3	1200	6

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
D	2	12	N	5	0.15	2	2520	12.6
D	2	12	N	5	0.15	3	2280	11.4
D	2	3	Y	2	0.1	2	1340	6.7
D	2	3	Y	2	0.1	3	2950	14.75
D	2	1	Y	2	0.09	2	2730	13.65
D	2	1	Y	2	0.09	3	1170	5.85
D	2	4	N	2	0.1	2	2770	13.85
D	2	4	N	2	0.1	3	2330	11.65
D	2	11	Y	5	0.15	2	2350	11.75
D	2	11	Y	5	0.15	3	3430	17.15
D	2	18	N	8	0.15	2	2345	11.725
D	2	18	N	8	0.15	3	2460	12.3
D	2	8	N	5	0.09	2	NA	NA
D	2	8	N	5	0.09	3	1770	8.85
D	2	6	N	2	0.15	2	3550	17.75
D	2	6	N	2	0.15	3	2920	14.6
D	2	10	N	5	0.1	2	2560	12.8
D	2	10	N	5	0.1	3	2070	10.35
D	2	17	Y	8	0.15	2	2270	11.35
D	2	17	Y	8	0.15	3	2690	13.45
D	2	9	Y	5	0.1	2	1610	8.05
D	2	9	Y	5	0.1	3	3810	19.05
D	2	14	N	8	0.09	2	4540	22.7
D	2	14	N	8	0.09	3	1450	7.25
D	2	2	N	2	0.09	2	2855	14.275
D	2	2	N	2	0.09	3	3290	16.45
D	2	7	Y	5	0.09	2	1730	8.65
D	2	7	Y	5	0.09	3	1950	9.75
D	2	15	Y	8	0.1	2	2020	10.1
D	2	15	Y	8	0.1	3	2135	10.675
D	2	13	Y	8	0.09	2	2305	11.525
D	2	13	Y	8	0.09	3	1780	8.9
D	2	16	N	8	0.1	2	2400	12
D	2	16	N	8	0.1	3	2080	10.4
D	2	5	Y	2	0.15	2	1250	6.25
D	2	5	Y	2	0.15	3	3850	19.25

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
D	3	1	Y	2	0.09	2	2430	12.15
D	3	1	Y	2	0.09	3	1270	6.35
D	3	7	Y	5	0.09	2	2650	13.25
D	3	7	Y	5	0.09	3	1440	7.2
D	3	3	Y	2	0.1	2	1910	9.55
D	3	3	Y	2	0.1	3	1670	8.35
D	3	16	N	8	0.1	2	2320	11.6
D	3	16	N	8	0.1	3	2080	10.4
D	3	9	Y	5	0.1	2	2130	10.65
D	3	9	Y	5	0.1	3	1790	8.95
D	3	10	N	5	0.1	2	2040	10.2
D	3	10	N	5	0.1	3	2550	12.75
D	3	4	N	2	0.1	2	2550	12.75
D	3	4	N	2	0.1	3	2430	12.15
D	3	15	Y	8	0.1	2	1960	9.8
D	3	15	Y	8	0.1	3	3600	18
D	3	17	Y	8	0.15	2	2140	10.7
D	3	17	Y	8	0.15	3	3230	16.15
D	3	13	Y	8	0.09	2	2210	11.05
D	3	13	Y	8	0.09	3	1570	7.85
D	3	6	N	2	0.15	2	3840	19.2
D	3	6	N	2	0.15	3	2500	12.5
D	3	11	Y	5	0.15	2	1955	9.775
D	3	11	Y	5	0.15	3	1625	8.125
D	3	12	N	5	0.15	2	2450	12.25
D	3	12	N	5	0.15	3	2700	13.5
D	3	5	Y	2	0.15	2	2130	10.65
D	3	5	Y	2	0.15	3	1000	5
D	3	18	N	8	0.15	2	2500	12.5
D	3	18	N	8	0.15	3	2860	14.3
D	3	2	N	2	0.09	2	4230	21.15
D	3	2	N	2	0.09	3	2090	10.45
D	3	14	N	8	0.09	2	4220	21.1
D	3	14	N	8	0.09	3	0	0
D	3	8	N	5	0.09	2	3710	18.55
D	3	8	N	5	0.09	3	1720	8.6

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
D	4	6	N	2	0.15	2	2935	14.675
D	4	6	N	2	0.15	3	2565	12.825
D	4	18	N	8	0.15	2	2650	13.25
D	4	18	N	8	0.15	3	1980	9.9
D	4	7	Y	5	0.09	2	2210	11.05
D	4	7	Y	5	0.09	3	2090	10.45
D	4	16	N	8	0.1	2	2460	12.3
D	4	16	N	8	0.1	3	2585	12.925
D	4	12	N	5	0.15	2	2600	13
D	4	12	N	5	0.15	3	2060	10.3
D	4	14	N	8	0.09	2	3000	15
D	4	14	N	8	0.09	3	3370	16.85
D	4	2	N	2	0.09	2	2580	12.9
D	4	2	N	2	0.09	3	2310	11.55
D	4	13	Y	8	0.09	2	2280	11.4
D	4	13	Y	8	0.09	3	2460	12.3
D	4	4	N	2	0.1	2	2300	11.5
D	4	4	N	2	0.1	3	2120	10.6
D	4	9	Y	5	0.1	2	2090	10.45
D	4	9	Y	5	0.1	3	1570	7.85
D	4	3	Y	2	0.1	2	2200	11
D	4	3	Y	2	0.1	3	2070	10.35
D	4	5	Y	2	0.15	2	2160	10.8
D	4	5	Y	2	0.15	3	2515	12.575
D	4	1	Y	2	0.09	2	2450	12.25
D	4	1	Y	2	0.09	3	2170	10.85
D	4	8	N	5	0.09	2	1050	5.25
D	4	8	N	5	0.09	3	3590	17.95
D	4	10	N	5	0.1	2	2510	12.55
D	4	10	N	5	0.1	3	2315	11.575
D	4	15	Y	8	0.1	2	2570	12.85
D	4	15	Y	8	0.1	3	2320	11.6
D	4	17	Y	8	0.15	2	2410	12.05
D	4	17	Y	8	0.15	3	2320	11.6
D	4	11	Y	5	0.15	2	1465	7.325
D	4	11	Y	5	0.15	3	1870	9.35

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
F	1	6	N	2	0.15	2	2460	12.3
F	1	6	N	2	0.15	3	4620	23.1
F	1	5	Y	2	0.15	2	2200	11
F	1	5	Y	2	0.15	3	2090	10.45
F	1	9	Y	5	0.1	2	2410	12.05
F	1	9	Y	5	0.1	3	2830	14.15
F	1	8	N	5	0.09	2	2960	14.8
F	1	8	N	5	0.09	3	3550	17.75
F	1	18	N	8	0.15	2	2210	11.05
F	1	18	N	8	0.15	3	2510	12.55
F	1	12	N	5	0.15	2	2270	11.35
F	1	12	N	5	0.15	3	1875	9.375
F	1	15	Y	8	0.1	2	2475	12.375
F	1	15	Y	8	0.1	3	2810	14.05
F	1	16	N	8	0.1	2	2390	11.95
F	1	16	N	8	0.1	3	2000	10
F	1	14	N	8	0.09	2	4710	23.55
F	1	14	N	8	0.09	3	4500	22.5
F	1	10	N	5	0.1	2	2330	11.65
F	1	10	N	5	0.1	3	2520	12.6
F	1	11	Y	5	0.15	2	1900	9.5
F	1	11	Y	5	0.15	3	2435	12.175
F	1	3	Y	2	0.1	2	2130	10.65
F	1	3	Y	2	0.1	3	3710	18.55
F	1	4	N	2	0.1	2	2715	13.575
F	1	4	N	2	0.1	3	2830	14.15
F	1	2	N	2	0.09	2	4290	21.45
F	1	2	N	2	0.09	3	3610	18.05
F	1	17	Y	8	0.15	2	1710	8.55
F	1	17	Y	8	0.15	3	4090	20.45
F	1	1	Y	2	0.09	2	1910	9.55
F	1	1	Y	2	0.09	3	3310	16.55
F	1	7	Y	5	0.09	2	1600	8
F	1	7	Y	5	0.09	3	660	3.3
F	1	13	Y	8	0.09	2	1950	9.75
F	1	13	Y	8	0.09	3	830	4.15

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
F	2	12	N	5	0.15	2	2200	11
F	2	12	N	5	0.15	3	2850	14.25
F	2	2	N	2	0.09	2	2820	14.1
F	2	2	N	2	0.09	3	4610	23.05
F	2	9	Y	5	0.1	2	970	4.85
F	2	9	Y	5	0.1	3	2250	11.25
F	2	10	N	5	0.1	2	2430	12.15
F	2	10	N	5	0.1	3	2460	12.3
F	2	17	Y	8	0.15	2	2230	11.15
F	2	17	Y	8	0.15	3	2945	14.725
F	2	3	Y	2	0.1	2	1600	8
F	2	3	Y	2	0.1	3	1635	8.175
F	2	11	Y	5	0.15	2	1230	6.15
F	2	11	Y	5	0.15	3	2520	12.6
F	2	8	N	5	0.09	2	2650	13.25
F	2	8	N	5	0.09	3	1840	9.2
F	2	1	Y	2	0.09	2	2350	11.75
F	2	1	Y	2	0.09	3	1360	6.8
F	2	18	N	8	0.15	2	2560	12.8
F	2	18	N	8	0.15	3	2790	13.95
F	2	14	N	8	0.09	2	3480	17.4
F	2	14	N	8	0.09	3	3280	16.4
F	2	15	Y	8	0.1	2	1860	9.3
F	2	15	Y	8	0.1	3	2360	11.8
F	2	13	Y	8	0.09	2	2980	14.9
F	2	13	Y	8	0.09	3	2500	12.5
F	2	7	Y	5	0.09	2	950	4.75
F	2	7	Y	5	0.09	3	2350	11.75
F	2	16	N	8	0.1	2	2500	12.5
F	2	16	N	8	0.1	3	2530	12.65
F	2	4	N	2	0.1	2	2500	12.5
F	2	4	N	2	0.1	3	2730	13.65
F	2	5	Y	2	0.15	2	1480	7.4
F	2	5	Y	2	0.15	3	1780	8.9
F	2	6	N	2	0.15	2	2630	13.15
F	2	6	N	2	0.15	3	2430	12.15

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
F	3	9	Y	5	0.1	2	2080	10.4
F	3	9	Y	5	0.1	3	2450	12.25
F	3	1	Y	2	0.09	2	2535	12.675
F	3	1	Y	2	0.09	3	3490	17.45
F	3	6	N	2	0.15	2	2910	14.55
F	3	6	N	2	0.15	3	3440	17.2
F	3	18	N	8	0.15	2	2710	13.55
F	3	18	N	8	0.15	3	3000	15
F	3	10	N	5	0.1	2	2460	12.3
F	3	10	N	5	0.1	3	2730	13.65
F	3	17	Y	8	0.15	2	2370	11.85
F	3	17	Y	8	0.15	3	2370	11.85
F	3	3	Y	2	0.1	2	1830	9.15
F	3	3	Y	2	0.1	3	2300	11.5
F	3	8	N	5	0.09	2	2720	13.6
F	3	8	N	5	0.09	3	3190	15.95
F	3	15	Y	8	0.1	2	2630	13.15
F	3	15	Y	8	0.1	3	2570	12.85
F	3	12	N	5	0.15	2	2500	12.5
F	3	12	N	5	0.15	3	2690	13.45
F	3	11	Y	5	0.15	2	2620	13.1
F	3	11	Y	5	0.15	3	2600	13
F	3	13	Y	8	0.09	2	4710	23.55
F	3	13	Y	8	0.09	3	3140	15.7
F	3	5	Y	2	0.15	2	2200	11
F	3	5	Y	2	0.15	3	2710	13.55
F	3	14	N	8	0.09	2	3580	17.9
F	3	14	N	8	0.09	3	3060	15.3
F	3	4	N	2	0.1	2	2660	13.3
F	3	4	N	2	0.1	3	2540	12.7
F	3	2	N	2	0.09	2	3400	17
F	3	2	N	2	0.09	3	4310	21.55
F	3	16	N	8	0.1	2	2390	11.95
F	3	16	N	8	0.1	3	2670	13.35
F	3	7	Y	5	0.09	2	4705	23.525
F	3	7	Y	5	0.09	3	2100	10.5

Collector	Rep	Trt	Cloth	Slope (%)	Flow Rate (L/sec)	Pan	Volume (mL)	Percent
F	4	13	Y	8	0.09	2	3790	18.95
F	4	13	Y	8	0.09	3	2840	14.2
F	4	15	Y	8	0.1	2	2350	11.75
F	4	15	Y	8	0.1	3	2180	10.9
F	4	18	N	8	0.15	2	2510	12.55
F	4	18	N	8	0.15	3	2890	14.45
F	4	5	Y	2	0.15	2	2190	10.95
F	4	5	Y	2	0.15	3	3770	18.85
F	4	10	N	5	0.1	2	2330	11.65
F	4	10	N	5	0.1	3	2410	12.05
F	4	6	N	2	0.15	2	3150	15.75
F	4	6	N	2	0.15	3	4040	20.2
F	4	14	N	8	0.09	2	4440	22.2
F	4	14	N	8	0.09	3	3950	19.75
F	4	4	N	2	0.1	2	2600	13
F	4	4	N	2	0.1	3	3010	15.05
F	4	16	N	8	0.1	2	2580	12.9
F	4	16	N	8	0.1	3	2580	12.9
F	4	2	N	2	0.09	2	3210	16.05
F	4	2	N	2	0.09	3	3920	16.05
F	4	8	N	5	0.09	2	3500	19.6
F	4	8	N	5	0.09	3	2260	17.5
F	4	1	Y	2	0.09	2	2320	11.3
F	4	1	Y	2	0.09	3	1780	11.6
F	4	12	N	5	0.15	2	2720	8.9
F	4	12	N	5	0.15	3	3170	13.6
F	4	3	Y	2	0.1	2	2425	15.85
F	4	3	Y	2	0.1	3	1550	12.125
F	4	11	Y	5	0.15	2	2350	7.75
F	4	11	Y	5	0.15	3	2950	11.75
F	4	9	Y	5	0.1	2	2230	14.75
F	4	9	Y	5	0.1	3	1880	11.15
F	4	17	Y	8	0.15	2	2450	9.4
F	4	17	Y	8	0.15	3	2500	12.25
F	4	7	Y	5	0.09	2	2510	12.5
F	4	7	Y	5	0.09	3	1780	12.55

APPENDIX B. LABORATORY STATISTICAL ANALYSIS: CLOTH AND NON CLOTH TRIALS

Laboratory runoff Cloth and no-Cloth
The GLM Procedure

Class Level Information

Class	Levels	Values
Coll	3	C D F
Cloth	2	N Y
Flow	3	0.09 0.1 0.15
Slope	3	2 5 8
Basin	2	2 3

Number of Observations Read	432
Number of Observations Used	432

Dependent Variable: Percent

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	64	2821.628118	44.087939	4.08	<.0001
Error	367	3965.341444	10.804745		
Corrected Total	431	6786.969562			

R-Square	Coeff Var	Root MSE	Percent Mean
0.415742	27.61371	3.287057	11.90372

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Coll	2	449.6147681	224.8073840	20.81	<.0001
Rep(Coll)	3	63.4536645	21.1512215	1.96	0.1200
Cloth	1	500.7253681	500.7253681	46.34	<.0001
Coll*Mat	2	32.7820921	16.3910461	1.52	0.2207
Flow	2	92.5416066	46.2708033	4.28	0.0145
Coll*Flow	4	306.9575899	76.7393975	7.10	<.0001
Cloth*Flow	2	86.9629897	43.4814948	4.02	0.0187
Coll*cloth*Flow	4	88.4983527	22.1245882	2.05	0.0872
Slope	2	71.9023566	35.9511783	3.33	0.0370
Coll*Slope	4	122.2288556	30.5572139	2.83	0.0247
Cloth*Slope	2	215.9607953	107.9803976	9.99	<.0001
Coll*cloth*Slope	4	43.1094586	10.7773646	1.00	0.4088
Flow*Slope	4	99.7152774	24.9288194	2.31	0.0577
Coll*Flow*Slope	8	57.8283656	7.2285457	0.67	0.7189
Cloth*Flow*Slope	4	79.8063527	19.9515882	1.85	0.1193
Coll*Cloth*Flow*Slope	8	67.5963425	8.4495428	0.78	0.6188
Basin	1	4.9205348	4.9205348	0.46	0.5002
Coll*Basin	2	88.6563838	44.3281919	4.10	0.0173
Cloth*Basin	1	0.0917292	0.0917292	0.01	0.9266
Coll*Cloth*Basin	2	7.9811755	3.9905877	0.37	0.6914
Flow*Basin	2	340.2940591	170.1470296	15.75	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Coll	2	14.6676103	7.3338051	0.68	0.5079
Rep(Coll)	3	63.4536645	21.1512215	1.96	0.1200
Cloth	1	500.7253681	500.7253681	46.34	<.0001
Coll*Cloth	2	32.7820921	16.3910461	1.52	0.2207
Flow	2	92.5416066	46.2708033	4.28	0.0145
Coll*Flow	4	306.9575899	76.7393975	7.10	<.0001
Cloth*Flow	2	86.9629897	43.4814948	4.02	0.0187
Coll*Cloth*Flow	4	88.4983527	22.1245882	2.05	0.0872
Slope	2	71.9023566	35.9511783	3.33	0.0370
Coll*Slope	4	122.2288556	30.5572139	2.83	0.0247
Cloth*Slope	2	215.9607953	107.9803976	9.99	<.0001
Coll*Cloth*Slope	4	43.1094586	10.7773646	1.00	0.4088
Flow*Slope	4	99.7152774	24.9288194	2.31	0.0577
Coll*Flow*Slope	8	57.8283656	7.2285457	0.67	0.7189
Cloth*Flow*Slope	4	79.8063527	19.9515882	1.85	0.1193
Coll*Cloth*Flow*Slope	8	67.5963425	8.4495428	0.78	0.6188
Basin	1	4.9205348	4.9205348	0.46	0.5002
Coll*Basin	2	88.6563838	44.3281919	4.10	0.0173
Cloth*Basin	1	0.0917292	0.0917292	0.01	0.9266

Coll*Cloth*Basin	2	7.9811755	3.9905877	0.37	0.6914
Flow*Basin	2	340.2940591	170.1470296	15.75	<.0001

Tests of Hypotheses Using the Type III MS for Rep(Coll) as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Coll	2	14.66761026	7.33380513	0.35	0.7320

t Tests (LSD) for Percent

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error
rate.

Alpha	0.05
Error Degrees of Freedom	367
Error Mean Square	10.80475
Critical Value of t	1.96645
Least Significant Difference	0.622

Means with the same letter are not significantly different.

t Grouping	Mean	N	Cloth
A	12.9803	216	N
B	10.8271	216	Y

t Tests (LSD) for Percent

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error
rate.

Alpha	0.05

```
Error Degrees of Freedom          367
Error Mean Square            10.80475
Critical Value of t           1.96645
Least Significant Difference   0.7618
Means with the same letter are not significantly different.

  t
Groupi
  ng       Mean       N    Slope

A       12.2259     144    8
A
A       12.1571     144    2

B       11.3281     144    5
```

```
t Tests (LSD) for Percent

NOTE: This test controls the Type I comparisonwise error rate, not the
experimentwise error
rate.


Alpha                                0.05
Error Degrees of Freedom              367
Error Mean Square                10.80475
Critical Value of t               1.96645
Least Significant Difference       0.7618

Means with the same letter are not significantly different.

  t
Groupi
  ng            Mean       N    Flow

     A       12.3990     144    0.15
     A
B    A       12.0267     144    0.09
B
B            11.2855     144    0.1
```

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Coll	Flow	Percent LSMEAN	LSMEAN Number
C	0.09	10.2901042	1
C	0.1	10.3072917	2
C	0.15	12.0510417	3
D	0.09	10.7442708	4
D	0.1	11.3511458	5
D	0.15	12.4984375	6
F	0.09	15.0458333	7
F	0.1	12.1979167	8
F	0.15	12.6473958	9

Least Squares Means for effect Coll*Flow
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Percent

i/j	1	2	3	4	5	6	7	8	9
1		1.0000	0.1801	0.9990	0.8145	0.0299	<.0001	0.1066	0.0145
2	1.0000		0.1906	0.9993	0.8279	0.0323	<.0001	0.1137	0.0158
3	0.1801	0.1906		0.5810	0.9813	0.9991	0.0004	1.0000	0.9935
4	0.9990	0.9993	0.5810		0.9926	0.1842	<.0001	0.4299	0.1085
5	0.8145	0.8279	0.9813	0.9926		0.7402	<.0001	0.9415	0.5920
6	0.0299	0.0323	0.9991	0.1842	0.7402		0.0053	1.0000	1.0000
7	<.0001	<.0001	0.0004	<.0001	<.0001	0.0053		0.0009	0.0118
8	0.1066	0.1137	1.0000	0.4299	0.9415	1.0000	0.0009		0.9991
9	0.0145	0.0158	0.9935	0.1085	0.5920	1.0000	0.0118	0.9991	

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Coll	Slope	Percent LSMEAN	LSMEAN Number
C	2	10.8328125	1
C	5	11.3145833	2
C	8	10.5010417	3
D	2	11.7343750	4
D	5	10.6244792	5
D	8	12.2350000	6
F	2	13.9041667	7
F	5	12.0453125	8
F	8	13.9416667	9

Least Squares Means for effect Coll*Slope
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Percent

i/j	1	2	3	4	5	6	7	8	9
1		0.9985	0.9999	0.9174	1.0000	0.4819	0.0002	0.6775	0.0002
2	0.9985		0.9535	0.9995	0.9829	0.9078	0.0042	0.9756	0.0034
3	0.9999	0.9535		0.6566	1.0000	0.1968	<.0001	0.3439	<.0001
4	0.9174	0.9995	0.6566		0.7738	0.9981	0.0357	0.9999	0.0300
5	1.0000	0.9829	1.0000	0.7738		0.2869	<.0001	0.4629	<.0001
6	0.4819	0.9078	0.1968	0.9981	0.2869		0.2414	1.0000	0.2148
7	0.0002	0.0042	<.0001	0.0357	<.0001	0.2414		0.1279	1.0000
8	0.6775	0.9756	0.3439	0.9999	0.4629	1.0000	0.1279		0.1113
9	0.0002	0.0034	<.0001	0.0300	<.0001	0.2148	1.0000	0.1113	

Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Cloth	Flow	Percent LSMEAN	LSMEAN Number
N	0.09	13.6013889	1
N	0.1	11.7725694	2
N	0.15	13.5670139	3
Y	0.09	10.4520833	4
Y	0.1	10.7983333	5
Y	0.15	11.2309028	6

Least Squares Means for effect Cloth*Flow
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Percent

i/j	1	2	3	4	5	6
1		0.0119	1.0000	<.0001	<.0001	0.0003
2	0.0119		0.0146	0.1553	0.4811	0.9214
3	1.0000	0.0146		<.0001	<.0001	0.0004
4	<.0001	0.1553	<.0001		0.9886	0.7139
5	<.0001	0.4811	<.0001	0.9886		0.9692
6	0.0003	0.9214	0.0004	0.7139	0.9692	

Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Cloth	Slope	Percent LSMEAN	LSMEAN Number
N	2	14.2072917	1
N	5	11.7204861	2
N	8	13.0131944	3
Y	2	10.1069444	4
Y	5	10.9357639	5
Y	8	11.4386111	6

Least Squares Means for effect Cloth*Slope
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Percent

i/j	1	2	3	4	5	6
1		0.0001	0.2498	<.0001	<.0001	<.0001
2	0.0001		0.1734	0.0399	0.7072	0.9956
3	0.2498	0.1734		<.0001	0.0024	0.0487
4	<.0001	0.0399	<.0001		0.6562	0.1484
5	<.0001	0.7072	0.0024	0.6562		0.9418
6	<.0001	0.9956	0.0487	0.1484	0.9418	

Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Coll	Basin	Percent LSMEAN	LSMEAN Number
C	2	11.1295139	1
C	3	10.6361111	2
D	2	12.1094444	3
D	3	10.9531250	4
F	2	12.7923611	5
F	3	13.8017361	6

Least Squares Means for effect Coll*Basin
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Percent

i/j	1	2	3	4	5	6
1		0.9462	0.4743	0.9995	0.0307	<.0001
2	0.9462		0.0798	0.9924	0.0014	<.0001
3	0.4743	0.0798		0.2840	0.8135	0.0261
4	0.9995	0.9924	0.2840		0.0112	<.0001
5	0.0307	0.0014	0.8135	0.0112		0.4398
6	<.0001	<.0001	0.0261	<.0001	0.4398	

Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Flow	Basin	Percent LSMEAN	LSMEAN Number
0.09	2	13.2767361	1
0.09	3	10.7767361	2
0.1	2	11.2691667	3
0.1	3	11.3017361	4
0.15	2	11.4854167	5
0.15	3	13.3125000	6

Least Squares Means for effect Flow*Basin
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Percent

i/j	1	2	3	4	5	6
1		0.0001	0.0038	0.0048	0.0148	1.0000
2	0.0001		0.9466	0.9306	0.7885	<.0001
3	0.0038	0.9466		1.0000	0.9988	0.0030
4	0.0048	0.9306	1.0000		0.9994	0.0038
5	0.0148	0.7885	0.9988	0.9994		0.0120
6	1.0000	<.0001	0.0030	0.0038	0.0120	

APPENDIX C. LABORATORY STATISTICAL ANALYSIS: CLOTH TRIALS ONLY

Laboratory runoff collector study 1: Cloth only
The GLM Procedure

Class Level Information

Class	Levels	Values
Coll	3	C D F
basin	2	2 3
Flow	3	0.09 0.1 0.15
Slope	3	2 5 8

Number of Observations Read	216
Number of Observations Used	216

The GLM Procedure

Dependent Variable: Percent

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	56	1065.265131	19.022592	1.72	0.0047
Error	159	1757.752241	11.055046		
Corrected Total	215	2823.017372			

R-Square	Coeff Var	Root MSE	Percent Mean
0.377350	30.70128	3.324913	10.82988

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Coll	2	168.7002120	84.3501060	7.63	0.0007
Rep(Coll)	3	64.3045902	21.4348634	1.94	0.1255
Flow	2	18.1235627	9.0617814	0.82	0.4424
Coll*Flow	4	75.9050838	18.9762709	1.72	0.1489
Slope	2	64.2543336	32.1271668	2.91	0.0576
Coll*Slope	4	122.1218025	30.5304506	2.76	0.0296
Flow*Slope	4	7.1998685	1.7999671	0.16	0.9569
Coll*Flow*Slope	8	43.9514870	5.4939359	0.50	0.8571
basin	1	1.9465510	1.9465510	0.18	0.6753
Coll*basin	2	35.5527861	17.7763931	1.61	0.2035
basin*Flow	2	374.8807757	187.4403878	16.96	<.0001
Coll*basin*Flow	4	16.2334819	4.0583705	0.37	0.8318
basin*Slope	2	4.1292965	2.0646483	0.19	0.8298

Coll*basin*Slope	4	13.7367632	3.4341908	0.31	0.8706
basin*Flow*Slope	4	10.9498778	2.7374694	0.25	0.9108
Coll*basi*Flow*Slope	8	43.2746583	5.4093323	0.49	0.8625

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Coll	2	6.3422020	3.1711010	0.29	0.7510
Rep(Coll)	3	64.3045902	21.4348634	1.94	0.1255
Flow	2	18.1235627	9.0617814	0.82	0.4424
Coll*Flow	4	75.9050838	18.9762709	1.72	0.1489
Slope	2	64.2543336	32.1271668	2.91	0.0576
Coll*Slope	4	122.1218025	30.5304506	2.76	0.0296
Flow*Slope	4	7.1998685	1.7999671	0.16	0.9569
Coll*Flow*Slope	8	43.9514870	5.4939359	0.50	0.8571
basin	1	1.9465510	1.9465510	0.18	0.6753
Coll*basin	2	35.5527861	17.7763931	1.61	0.2035
basin*Flow	2	374.8807757	187.4403878	16.96	<.0001
Coll*basin*Flow	4	16.2334819	4.0583705	0.37	0.8318
basin*Slope	2	4.1292965	2.0646483	0.19	0.8298
Coll*basin*Slope	4	13.7367632	3.4341908	0.31	0.8706
basin*Flow*Slope	4	10.9498778	2.7374694	0.25	0.9108
Coll*basi*Flow*Slope	8	43.2746583	5.4093323	0.49	0.8625

Tests of Hypotheses Using the Type III MS for Rep(Coll) as an Error Term

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Coll	2	6.34220201	3.17110100	0.15	0.8684

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

Coll	Slope	Percent LSMEAN	LSMEAN Number
C	2	8.1531250	1
C	5	11.3072917	2
C	8	9.8052083	3
D	2	10.3437500	4
D	5	10.5104167	5
D	8	11.5897917	6
F	2	11.8489583	7
F	5	10.9895833	8
F	8	12.9208333	9

Least Squares Means for effect Coll*Slope
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Percent

i/j	1	2	3	4	5	6	7	8	9
1		0.0332	0.7326	0.3591	0.2618	0.0132	0.0052	0.0837	<.0001
2	0.0332		0.8222	0.9851	0.9958	1.0000	0.9997	1.0000	0.7572
3	0.7326	0.8222		0.9998	0.9982	0.6425	0.4573	0.9477	0.0374
4	0.3591	0.9851	0.9998		1.0000	0.9306	0.8205	0.9990	0.1617
5	0.2618	0.9958	0.9982	1.0000		0.9697	0.8984	0.9999	0.2346
6	0.0132	1.0000	0.6425	0.9306	0.9697		1.0000	0.9994	0.9013
7	0.0052	0.9997	0.4573	0.8205	0.8984	1.0000		0.9930	0.9709
8	0.0837	1.0000	0.9477	0.9990	0.9999	0.9994	0.9930		0.5373
9	<.0001	0.7572	0.0374	0.1617	0.2346	0.9013	0.9709	0.5373	

The GLM Procedure
Least Squares Means
Adjustment for Multiple Comparisons: Tukey

basin	Flow	Percent LSMEAN	LSMEAN Number
2	0.09	12.4326389	1
2	0.1	10.3806944	2
2	0.15	9.9611111	3
3	0.09	8.6812500	4
3	0.1	11.0229167	5
3	0.15	12.5006944	6

Least Squares Means for effect basin*Flow
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: Percent

i/j	1	2	3	4	5	6
1		0.0988	0.0233	<.0001	0.4695	1.0000
2	0.0988		0.9946	0.2584	0.9636	0.0798
3	0.0233	0.9946		0.5780	0.7537	0.0179
4	<.0001	0.2584	0.5780		0.0376	<.0001
5	0.4695	0.9636	0.7537	0.0376		0.4148
6	1.0000	0.0798	0.0179	<.0001	0.4148	

APPENDIX D. COLLECTOR DIMENSIONS

Collector	Unit	Body (mm)	Chute (mm)	Actual percent	Pan
C	1	303	32	10.56	2
C	3	310	34	10.97	3
C	5	325	32	9.85	*
			AVG	**10.46**	
D	1	303	32	10.56	2
D	3	309	34	11.00	3
D	5	324	34	10.49	*
			AVG	**10.69**	
F	1	305	33	10.82	2
F	3	322	34	10.56	3
F	5	323	34	10.53	*
			AVG	**10.63**	

* Not used in laboratory study

APPENDIX E. THEORETICAL VS. OBSERVED T-TESTS

Coll C pan 2 Cloth t-tests

The TTEST Procedure

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	9.0976	10.135	11.173	2.4878	3.0672	4.001	0.5112

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	-0.83	**0.4119**

Coll C pan 2 NO Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	11.2	12.124	13.047	2.214	2.7297	3.5607	0.4549

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	3.44	**0.0015**

Coll C pan 3 Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	8.2464	9.375	10.504	2.7054	3.3355	4.351	0.5559

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	-2.87	**0.0069**

Coll C pan 3 NO Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	10.66	11.897	13.135	2.9666	3.6575	4.771	0.6096

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	1.52	**0.1372**

Coll D pan 2 Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	10.357	11.198	12.039	2.0156	2.4851	3.2417	0.4142

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	1.54	**0.1324**

Coll D pan 2 NO Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	35	11.885	13.393	14.901	3.5508	4.3899	5.7516	0.742

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	34	3.82	**0.0005**

Coll D pan 3 Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	9.0401	10.431	11.822	3.3349	4.1117	5.3634	0.6853

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	-0.83	**0.4122**

Coll D pan 3 NO Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	9.9386	11.475	13.011	3.6829	4.5407	5.9231	0.7568

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	0.63	**0.5343**

Coll F pan 2 Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	10.025	11.376	12.728	3.2393	3.9937	5.2096	0.6656

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	0.84	**0.4089**

Coll F pan 2 NO Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	13.247	14.301	15.354	2.5255	3.1137	4.0616	0.5189

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	6.71	**<.0001**

Coll F pan 3 Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	11.103	12.419	13.735	3.1547	3.8895	5.0736	0.6483

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	2.87	**0.0070**

Coll F pan 3 NO Cloth t-tests

Variable	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
Percent	36	13.839	15.112	16.385	3.0517	3.7625	4.908	0.6271

T-Tests

Variable	DF	t Value	Pr > |t|
Percent	35	7.26	**<.0001**

APPENDIX F. 2005 FIELD ANALYSIS

2005 Lancaster field data

The Mixed Procedure

Model Information

Data Set	WORK.SEDIMENT
Dependent Variable	sed
Covariance Structure	Variance Components
Estimation Method	REML
Residual Variance Method	Profile
Fixed Effects SE Method	Model-Based
Degrees of Freedom Method	Containment

Class Level Information

Class	Levels	Values
Date	6	19-Aug 19-Sep 26-Jul 27-Jun 29-Jul 6-Jun
trt	2	ch st

Dimensions

Covariance Parameters	2
Columns in X	12
Columns in Z	6
Subjects	1
Max Obs Per Subject	21

Number of Observations

Number of Observations Read	21
Number of Observations Used	21
Number of Observations Not Used	0

Iteration History

Iteration	Evaluations	-2 Res Log Like	Criterion
0	1	-25.22581271	
1	1	173.30062025	0.00000000

Convergence criteria met but final hessian is not positive definite.

Covariance Parameter Estimates

Cov Parm	Estimate
Date	5.505E11
Residual	0.002349

Fit Statistics

-2 Res Log Likelihood	173.3
AIC (smaller is better)	177.3
AICC (smaller is better)	179.0
BIC (smaller is better)	176.9

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
trt(Date)	10	10	1.37	0.3153

APPENDIX G. COLLECTOR FIELD SETUP PHOTOGRAPH

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